Causes and Effects of Coastal Hypoxia Worldwide: Putting the Louisiana Shelf Events in Perspective

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Abstract

Global Patterns of Benthic Hypoxia and Anoxia: Causes, Responses, and Altered Energy Flows

Synthesis of literature pertaining to benthic hypoxia and anoxia (Diaz and Rosenberg, 1995) revealed that community and population responses to low dissolved oxygen stress were similar across all ecosystems and followed a hierarchical pattern. The occurrence of hypoxia and anoxia is expanding with significant structural and functional changes in affected benthic communities. Benthic-pelagic coupling is also adversely affected. No other environmental variable of such ecological importance to coastal marine ecosystems around the world has changed so drastically in such a short period as dissolved oxygen. While hypoxic and anoxic environments have existed through geological time, their occurrence in shallow coastal and estuarine areas appears to be increasing, most likely accelerated by human activities. The oxygen budgets of most major coastal ecosystems have been adversely affected mainly through the process of eutrophication, which acts as an accelerant or enhancing factor to hypoxia and anoxia. Many ecosystems that are now severely stressed by hypoxia appear to be near or at a threshold of imminent collapse (loss of fisheries, loss of biodiversity, lower system ascendancy).

Introduction

No other environmental variable of such ecological importance to coastal marine ecosystems around the world has changed so drastically in such a short period as dissolved oxygen. While hypoxic and anoxic environments have existed through geological time, their occurrence in shallow coastal and estuarine areas appears to be increasing, most likely accelerated by human activities. Synthesis of literature pertaining to benthic hypoxia and anoxia (Diaz and Rosenberg, 1995) revealed that the oxygen budgets of most major coastal ecosystems have been adversely affected mainly through the process of eutrophication, which acts as an accelerant or enhancing factor to hypoxia and anoxia. Many ecosystems that are now severely stressed by hypoxia appear to be near or at a threshold of imminent collapse (loss of fisheries, loss of biodiversity, lower system ascendancy). Hypoxic events on the Louisiana shelf will be discussed relative to world wide problems with low dissolved oxygen.

System Summaries

Limfjorden, Denmark

- Experiences seasonal summertime hypoxia.
- Oxycline can be sharp with >5.6 ml/l at 0.5 m and 0.4 ml/l at 0.05m above the bottom.

- Annual mass mortality and recolonization occurs.
- Also, Beggiatoa spp. occur in some areas all year.

Gullmarsfjord, Sweden

- Oxygen concentration has declined gradually from the 1950's but remained above 2 ml/l.
  - Fauna appeared stable up to 1979.
- During the winter of 1979 severe Hypoxia occurred, reaching 0.8 ml/l.
  - Fauna remained stable.
- Hypoxia continued and in January 1980 hypoxia reached 0.2 ml/l.
  - Mass mortality of fauna occurred.

Upwelling & Oxygen Minimum Zone

- Stable hypoxia associated with high quality organics.
- Leads to low diversity, but stable high abundance and biomass fauna.

Kiel Bay, Germany

- A declining trend in dissolved oxygen has been observed since 1950's.
- Periodic hypoxia began in the 1960's.
  - Mortality of fauna was observed.
- In 1981 and 1983 severe hypoxia occurred.
  - Mass mortality of fauna.
  - Shift in fauna to opportunistic species.
- The 1981 event was widespread in all parts of Kiel Bay, with H_2S and Anoxia at > 20 m.
  - Event was several weeks long.
- The result was mass mortality of benthos, 99 percent of biomass died.
  - 30,000 mt of macrofauna died, 750 km^2.

Kattegat, Sweden-Denmark

- Classic description of benthic communities from this area. Fisheries well developed.
- By the 1970's there was speculation that the ecosystem was not doing well.
- Annual hypoxia began in 1980.
  - First observations of fish and benthos mortality.
  - 1984 record high catches in trawl fisheries.
- Hypoxia was severe by 1985 and worsening.
  - Mortality of benthos, fisheries reduced to low levels.
- In 1988, 3,000 km^2 affected.
  - Mass mortality of benthos and fisheries, poor recovery.

LA-TX Continental Shelf

- Chronic mild hypoxia may have existed, no long-term data.
- The first measured hypoxic event was in 1973.
  - Reductions in fauna.
  - No mass mortality.
- In 1978 severe hypoxia occurred.
  - Mass mortality of benthos.
  - Shift to opportunistic species.
  - Low fishery catches.

- Currently 8,000–9,500 km^2 are affected annually.
  - Mass mortality of benthos.
  - Low fishery catches.

Black Sea

- Average depth of 1270 m, the largest mass of "naturally occurring" permanently anoxic water on earth.
- About 90 percent of its 5.4 × 105 km^3 volume is anoxic beginning at depths of 150 to 250 m.
- Permanently hypoxic below about 100 m
- Ukrainian northwestern Black Sea shelf is critically eutrophic, periodic hypoxia and anoxia is wide-spread encompassing all of the Sea of Azov and up to 95 percent of the Ukrainian northwestern shelf.
- Periodic events are distinct from the permanent anoxic layer and lead to mass mortalities of benthic populations that colonize the area during normoxic periods.
- In 1991, anoxia along the Romanian coast eliminated an estimated 50 percent of the demersal fish populations.
- Since the 1960's increasing hypoxia and anoxia have been blamed for the replacement of the highly valued demersal fish species with planktic omnivores.
- Of the 26 commercial species fished in the 1960's only 6 still support a fishery.

Baltic Sea

- Trend of declining oxygen concentrations was documented from the 1930's to the late 1960's in the deep basins.
- Beginning in the 1960's and lasting up to the present, large deep bottom areas of the Baltic Sea have been mostly permanently hypoxic or anoxic and devoid of benthic macrofauna.
- Below the halocline, at about 70 m, approximately 100000 km2 of the bottom is more or less permanently hypoxic.
- No significant change in the bottom water oxygen content has occurred up to 1993.
- Biomass "missing" in the anoxic areas estimated to be 1.7 × 106 t wet wt
- Periodic hypoxia in the mesohaline Bornholm Basin in the south Baltic was reported as early as 1948.
- Benthic communities were reduced and even eliminated during periods of hypoxia or anoxia and how bottoms were recolonized following a subsequent return of normoxia.

Reference

Diaz, R.J. and R. Rosenberg. (In Press) Marine benthic hypoxia—review of ecological effects and behavioral responses on macrofauna. Oceanogr. Mar. Biol. Ann. Rev., vol. 33.

Presentation Discussion

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No questions/discussion following Mr. Diaz presentation

Table 5.

Summary of benthic effects for hypoxic systems around the world. Several of these systems also experience anoxia. In the case of many fjords, and coastal and oceanic oxygen minimum zones (OMZ) there is an anoxic zone within which no macrofauna occur. The absence of fauna from these anoxic zones is not considered a community response but a consequence of stable anoxia. Hypoxia is typed as: Aperiodic—events that are known to occur at irregular intervals greater than a year; Periodic—events occurring at regular intervals shorter than a year, related to tidal stratification/destratification cycles (Haas, 1977); Seasonal—yearly events relate to summer or autumnal stratification; Persistent—year-round hypoxia. Levels of hypoxia are: Moderate— oxygen decline to about 0.5 ml/l; Severe—decline to near anoxic levels, could also become anoxic. Time trends of hypoxia, areal and or intensity, for the systems are: -= Improving conditions; + = Gradually increasing; ++ = rapidly increasing; 0 = stable; . = no temporal data. Benthic community response is categorized as: None—communities appear similar before and after hypoxic event; mortality—moderate reductions of populations, many species survive; Mass Mort.—drastic reduction or elimination of the benthos. Benthic recovery is: No change—dynamics appear unrelated to hypoxia; Some—recolonization occurs but community does not return to prehypoxic structure; Slow—gradual return of community structure taking more than a year; Annual—recolonization and return of community structure within a year.

		System Level Response to Hypoxia						
No.	System	Hypoxia Type	Hypoxia Level	Time Trends	Bent. Com. Response	Benthic Recovery	Fisheries Stocks	Reference
1	Deep Texas Shelf	Aperiodic	Moderate	0?	Mortality	Annual	Stressed	Harper et al. 1981, 1991
2	German Bight, North Sea	Aperiodic	Mod./Severe	+	Mass Mort.	Annual	.	Dethlefsen & Westernhgen 1983
3	New York Bight, New Jersey	Aperiodic	Severe	.	Mass Mort.	Slow	Surf Clam losses	Boesch & Rosenberg 1981, Garlo et al. 1979, Sindermann & Swanson 1980
4	Shallow Texas Shelf	Aperiodic	Severe	+	Mass Mort.	Slow	Stressed	Harper et al. 1981, 1991
5	Sommone Bay, France	Aperiodic	Severe	+?	Mass Mort.	Slow	Collapse of Cockle fishery	Desprez et al. 1992
6	North Sea, W. Denmark	Aperiodic	Severe	+	Mortality	Annual	Stressed	Dyer et al. 1983, Westernhagen & Dethlefson 1983
7	Peru/Chile, El Niño, shallow	Aperiodic	Severe	0?	Mass Mort.	???	Stressed	Rosenberg et al. 1983, Arntz & Fahrbach 1991
8	York River, Virginia	Periodic	Mod./Severe	0	None	No Change	Stressed	Pihl et al. 1991, Diaz et al. 1993
9	Rappahannock River, Virginia	Periodic	Severe	+	Mortality	Annual	Stressed	Llansó 1990
10	Seto Inland Sea, Japan	Seasonal	Moderate	.	Mortality	Annual	.	Imabayashi 1986
11	Louisianna Shelf	Seasonal	Mod./Severe	+	Mortality	Annual	Stressed	Boesch&Rabalais 91, Rabalais et al.1991
12	Saanich Inlet, British Columbia	Seasonal	Mod./Severe	0	Mortality	Annual	.	Tunnicliffe 1981
16	German Bight, North Sea	Seasonal	Severe	+?	Mortality	Annual	Stressed	Niermann et al. 1990
17	Main Chesapeake Bay, MD	Seasonal	Severe	+	Mortality	Annual	Stressed	Holland et al. 1987
18	Port Hacking, Australia	Seasonal	Severe	.	Mortality	Annual	.	Rainer & Fitzhardinge 1981
19	Tolo Harbor, Hong Kong	Seasonal	Severe	.	Mass Mort.	Annual	.	Wu 1982
20	Tome Cove, Japan	Seasonal	Severe	.	Mortality	Annual	.	Tsutsumi 1987
21	Laholm Bay, Sweden	Seasonal	Severe	++	Mortality	Annual	Stressed	Baden et al. 1990b, Rosenberg & Loo 1988
22	Gullmarsfjord, Sweden	Seasonal	Severe	+	Mass Mort.	Annual	Stressed	Josefson & Widbom 1988
23	Swedish West Coast Fjords	Seasonal	Severe	++	Mortality	Some	Stressed	Josefsen & Rosenberg 1988
24	Pamlico River, North Carolina	Seasonal	Severe	.	Mass Mort.	Annual	.	Tenore 1972
25	Limfjord, Denmark	Seasonal	Severe	+	Mass Mort.	Annual	None	Jørgensen 1980
26	Kiel Bay, Germany	Seasonal	Severe	+	Mass Mort.	Annual	Stressed	Arntz 1981, Weigelt 1990
27	Lough Ine, Ireland	Seasonal	Severe	0	Mass Mort.	Annual	.	Kitching et al. 1976
28	Hillsborough Bay, Florida	Seasonal	Severe	.	Mass Mort.	Annual	.	Santos & Simon 1980
29	Gulf of Trieste, Adriatic	Seasonal	Severe	++	Mass Mort.	Slow	Stressed	Stachowitsch 1991
30	Elefsis Bay, Aegean Sea	Seasonal	Severe	.	Mass Mort.	Annual	.	Friligos and Zenetos 1988
31	Black Sea NW Shelf	Seasonal	Severe	++	Mass Mort.	Annual	Reduced	Zaitsev 1993
32	Århus Bay, Denmark	Seasonal	Severe	+	Mass Mort.	Slow	.	Fallesen & Jørgensen 1991
33	Loch Creran, Scotland	Persistent	Severe	0	Mass Mort.	No Change	.	Pearson 1981
34	Byfjord, Sweden	Persistent	Severe	0	Mortality	Some	Pelagic only	Rosenberg 1990
35	Black Sea (except NW shelf)	Persistent	Severe	+	No Benthos	No Change	Pelagic only	Tolmazin 1985, Mee 1992
36	Idefjord, Sweden-Norway	Persistent	Severe	+#	Mortality	Some	.	Rosenberg 1980
37	Baltic Sea, Central	Persistent	Severe	++	Mortality	Some	Stressed	Andersin et al. 1978
38	Fosa de Cariaco, Venezuela	Persistent	Severe	.	Reduced	No Change	.	Nichols 1976
39	Caspian Sea	Persistent	Mod./Severe	0	Mortality	Some?	.	Zenkevitch 1963
40	Peru/Chile Upwelling Deep	Persistent	Mod./Severe	0	Biomass Increase	No Change	Enhanced?	Arntz & Fahrbach 1991 Rosenberg et al. 1983
41	Santa Maria Basin, California	Persistent	Mod./Severe	0	Reduced	No Change	.	Hyland et al. 1991
42	Central California OMZ	Persistent	Mod./Severe	0	Biomass Increase	No Change	.	Mullins et al. 1985
43	Volcano 7, Pacific OMZ	Persistent	Mod./Severe	0	Biomass Increase	No Change	.	Levin et al. 1991
44	Gulf of Finland, Deep	Persistent	Mod./Severe	-	Reduced	Slow	.	Andersin & Sandler 1991

* Stable oxygen gradient associated with organic enrichment.

** These systems are currently in a persistent hypoxic state.

\# Recent imporvements in oxygen concentrations due to pollution abatement.